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TOTAL ENVIRONMENTAL CONTROL SYSTEMS; SOFT-START AND SOFT-START VARIABLE  
CAPACITY AIR CONDITIONERS

VSE Corporation  
2550 Huntington Avenue  
Alexandria, VA 22303-1499

15 November 1987

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Final Report for Period 15 April 1986 through 15 November 1987

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Prepared for:

U.S. Army Belvoir Research, Development and Engineering Center  
Environmental Control Division (STRBE-FE)  
Fort Belvoir, VA 22060-5606

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) VSE Corporation and a team of three subcontractors, developed, fabricated and delivered three Total Environmental Control Systems (TECS) (modified military air conditioners) to Belvoir for subsequent government evaluation. This developmental effort, based on the application of solid state electronic motor controllers to 18,000 BTUH GFE air conditioners, resulted in deliveries of two soft-start TECS; one soft-start variable capacity TECS; one feasibility study concerning the use of commercial off-the-shelf components in military standard air conditioners; and, one repackaging study to use electronic controllers in existing military standard air conditioner designs. VSE's principal task effort conclusions were: (a) Existing technology will support further TECS developmental efforts; (b) and, most commercial off-the-shelf components are not suitable for use in MIL-STD air conditioners. The principal recommendation was that Belvoir initiate an advanced development soft-start TECS task.				
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## SUMMARY

The Environmental Control Division of the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir), Fort Belvoir, VA, requested VSE Corporation to:

- o Modify three government furnished 18,000 BTUH (British Thermal Units per Hour) air conditioners to Soft-Start and Soft-Start Variable Capacity configurations. These modified air conditioners were then identified as Total Environmental Control Systems (TECS). The modifications involved removing a hot gas by-pass system and related piping from the air conditioner, and installing an electronic motor controller which yielded the following advantages:
  - a. The air conditioner can be used on any military 208V, 3-phase power supply, and will accept frequencies of 50 to 400 Hertz. With only one power type for each configuration, logistic advantages will result.
  - b. Major savings in energy costs will be realized because the soft-start feature permits stopping and starting the TECS unit in response to a thermostat. When no cooling is required, the unit demands very little energy. Existing conventionally controlled military units use at least 70% of full load power when they are in the by-pass mode (not producing any cooling).
  - c. The soft-start feature may permit down-sizing of supporting electric power generators and associated equipment.
- o Perform a feasibility study on installing commercial off-the-shelf compressors, fan motors, and other miscellaneous parts in 9,000, 18,000, and 36,000 BTUH horizontal and vertical compact air conditioners.
- o Perform a repackaging study to find space for installation of electronic motor controllers in 9,000, 18,000, and 36,000 BTUH horizontal and vertical compact air conditioners.

VSE's task approach was to use the combined expertise and capabilities of both in-house and subcontractor personnel and facilities. The Soft-Start Variable Capacity TECS was modified in-house with the assistance of two subcontractors who developed the necessary electronic motor controller and logic network subassemblies. Modifications resulting in two Soft-Start TECS units were accomplished by a third subcontractor. All three units were tested before delivery to Belvoir for subsequent evaluations.

As a result of this work effort, VSE's principal conclusions were:

- o Existing technology will support the modification of existing military standard air conditioners to the TECS configuration.

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- o The soft-start variable capacity TECS is considerably more complicated and expensive than a soft-start unit, and does not offer many additional advantages.
- o The soft-start TECS has major potential cost advantages which make it a very attractive alternative to the existing conventionally controlled military air conditioners.
- o Most commercial off-the-shelf components are not suitable for use in military standard air conditioners.
- o Existing military standard air conditioner designs can be "repackaged" to accommodate electronic motor controllers.

Principal recommendations for Belvoir's consideration were that:

- o Follow-on tasks be initiated for the advanced development of soft-start TECS air conditioners.
- o A rigidly controlled test program be initiated to verify the magnitude of energy savings of TECS units over existing conventionally controlled military standard air conditioner designs.

## PREFACE

This report was prepared under the authority of task order 0001 to Belvoir Research, Development and Engineering Center (Belvoir) Contract DAAK70-86-D-0023. Contract 0023 requires VSE Corporation to provide engineering and technical support for a wide range of projects being performed at Belvoir. Task order 0001 is concerned with developing Total Environmental Control Systems (TECS) using government furnished 18,000 BTUH air conditioners.

The authors of this report wish to acknowledge the very valuable contributions provided by Mr. Thomas J. Sgroi of Belvoir.

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## 1. INTRODUCTION

1.1 Statement of problems. The problems solved and discussed in this report were to:

- o Convert government furnished 18,000 BTUH (British Thermal Units per Hour) air conditioners to Soft-Start and Soft-Start Variable Capacity configurations.
- o Determine the feasibility of using off-the-shelf commercial compressors, fan motors and other miscellaneous parts in the 9,000, 18,000, and 36,000 BTUH military standard horizontal and vertical compact air conditioners.
- o Find space within the horizontal and vertical air conditioners for the installation of electronic motor controllers (inverters).

1.2 Background. There are three families of military standard air conditioners. They are:

- o Horizontal - 9K, 18K, 36K, and 60K BTUH capacities.
- o Vertical - 6K, 9K, 18K, 36K, and 60K BTUH capacities.
- o Split-Package - 18K BTUH capacity only.

All three air conditioner families use an across-the-line starting system in which the starting current may be more than five times the full load steady state operating current. The "soft-start" system, achieved by using electronic motor controllers (inverters), is defined as "operating the air conditioner such that the start-up current does not exceed full load steady state current required for the air conditioner (with controls)."

An air conditioner modified for soft-start or soft-start variable capacity is known as a Total Environmental Control System (TECS).

1.3 Purpose of report. The purpose of this report is document task order 0001 work performance for the:

- o Soft-start and soft-start variable capacity TECS development effort.
- o Feasibility study on installing commercial off-the-shelf components in military standard air conditioners (9K, 18K, 36K BTUH horizontal and vertical).
- o Repackaging study for insertion of electronic motor controllers - logic network units in military standard air conditioners. (9K, 18K, 36K BTUH horizontal and vertical).

Requirements for this report are established by Task Order 0001 to U.S. Army Belvoir Research, Development, and Engineering Center (Belvoir) Contract DAAK70-86-D-0023. This contract requires VSE Corporation to provide engineering and technical services for a wide range of Belvoir programs and projects.

1.4 Scope of report. This report covers the period of 15 April 1986 through 15 November 1987. It discusses both VSE and subcontractor work efforts for task completion.

1.5 Reference to related work. Task Order 0001 is related to task order 0074 of the same contract. Task Order 0074 concerns the TECS development for the 18K BTUH compact horizontal and vertical military compact family of air conditioners.

1.6 Disposition instructions. Destroy this report when no longer needed. Do not return it to the originator.

## 2. TECHNICAL REQUIREMENTS AND APPROACH

2.1 Technical requirements. Task order 0001, as modified, required VSE to:

- o Make engineering changes and modify three government furnished 18,000 BTUH air conditioners to electronically controlled soft-start and/or variable capacity configurations.
- o Perform a feasibility study concerned with substituting commercial off-the-shelf parts for military standard parts currently installed in 9K, 18K, and 36K BTUH horizontal and vertical compact air conditioners.
- o Perform a repackaging study to install selected commercial components and electronic motor controllers in 9K, 18K, and 36K BTUH horizontal and vertical compact air conditioners.

2.2 Technical approach. VSE's technical approach for performance of task order 0001 was to subcontract with companies having expertise and experience with similar and/or related task requirements. Following the selection of these subcontractors, and during the process of awarding contracts, one company withdrew their offer due to unforeseen schedule difficulties. VSE then assumed this particular workload. As this work progressed significant cost savings accrued, and the task order was modified to add the requirements for the feasibility study and the repackaging study.

The breakout of work performed by VSE and its subcontractors was:

- o VSE Corporation. Soft-Start Variable Capacity TECS; Hardware engineering, fabrication, component packaging, tests of completed unit.
- o Zycron Systems, Inc. Soft-Start Variable Capacity TECS; Electronic motor controller design, fabrication, and tests.
- o Maritime Dynamics, Inc. Soft-Start Variable Capacity TECS; Electronic logic network design, fabrication and tests. Integration and debugging of logic network and motor controller.



- o Keco Industries, Inc. Soft-Start TECS; Motor controller and logic network design, fabrication, module and unit tests, and technical support for government tests; feasibility study; repackaging study to include drawing packages.

### 3. DISCUSSION

3.1 Previous Total Environmental Control System (TECS) development. An early 1970s TECS development effort was hindered by the lack of adequate solid-state power transistors. More recent developments, which provide the technology base for the performance of this task order, are best summarized in the following extracts from a Keco Industries report prepared for VSE.

- o Progress in the field of solid-state, power-control equipment has greatly improved the reliability and reduced both the size and cost of inverters (motor controllers) in recent years. The application of a solid-state motor controller to the military ECU (Environmental Control Unit) offers significant benefits in the areas of logistics and energy conservation.
- o \* \* \* research has uncovered numerous additional benefits that would accrue from the inclusion of a motor controller in military-type air conditioning units. \* \* \* the inverter can provide ramping functions to provide soft starting of AC motors to reduce the high in-rush current levels of 500-600% full load to approximately equal to full load rated current level.
- o With the elimination of the high-level surge currents during start-up, it is no longer necessary to consider a form of reduced voltage start for the motors. This fact relieves us of the need to consider the expense of additional contactors, timing devices and autotransformers or resistors which are part of the traditional reduced voltage starter as applied to AC motors to limit in-rush current.
- o Since the compressor demands the highest level of power consumption, it is often the determining factor in the selection of a kilowatt rating for the generator supplying AC power to a shelter system. Therefore, the large reduction in the in-rush current requirement for AC motor starting permits (VSE added: generator) down sizing. This provides greater economy in installation and improvement in the logistics of transport and storage of fuel.
- o Furthermore, the ramp-start function allows any or all of the motors to cycle on and off with demand of the thermostat. This has a direct effect on the unit's operating time, resulting in longer life, less maintenance and substantially less energy consumption. Fuel consumption was the primary reason behind initiation of this study.

3.2 Focus of task order engineering changes and modifications. The focus for task order engineering changes and modifications was to evaluate and install electronic motor controllers, with logic networks, in three government furnished 18,000 BTUH air conditioners. Before modifications, two air

conditioners conformed to MIL-A-52963 (Split-Package, 208 VAC, 3-phase, 400 Hz). The third unit was a previously manufactured experimental TECS unit (Split-Package, 208 VAC, 3-phase, 400 Hz).

The use of an electronic motor controller and logic network makes it possible for MIL-A-52963 air conditioners to operate on both 50/60 Hz and 400 Hz external power by conversion to a soft-start 208 VAC, 3-phase, 61 Hz internal operating power. This power conversion would eliminate the need for:

- o 400 Hz motors and compressors designed solely for use with 400 Hz external power.
- o A hot gas bypass capacity control system that is part of the MIL-A-52963 air conditioner refrigeration system.

In addition to the power change and elimination of selected components, the engineering change and modification effort was to include the use of Built-In-Test-Equipment (BITE) in TECS units. Such equipment would announce and show the nature of major electrical and/or mechanical component failures and malfunctions.

### 3.3 Soft-start TECS

3.3.1 Work effort and requirements. Two military standard 18,000 BTUH split-package air conditioners, using conventional controls and a hot gas bypass system for capacity control, were modified to the soft-start TECS configuration. This work was performed by Keco Industries at their Florence, Kentucky facility. Both units were tested by Keco before they were shipped to government designated locations for subsequent government tests.

Specific requirements were to use electronic motor controllers and logic networks which would provide the soft-start TECS configuration. The function of the motor controller was to convert externally supplied 208 VAC, 3-phase, 50/60 Hz or 400 Hz power to soft-start 208 VAC, 3-phase, 61 Hz power for operation of the newly installed condenser and evaporator fan motors and compressor. The incorporation of BITE, and delivery of two spare motor controller - logic network units, an operator's manual, and operation and maintenance instructions were also required.

3.3.2 Major engineering changes and modifications. The major engineering changes and modifications resulting in the conversion of two MIL-A-52963 air conditioners to the soft-start TECS configuration were:

- o removal of unnecessary hardware:
  - hot gas bypass system with associated piping.
  - 400 Hz motors and compressor.
- o repackaging of retained hardware to accommodate new components.
- o installation of new components:
  - electronic motor controller and logic network.
  - BITE is reconfigured control panel.

- 50/60 Hz motors and compressor.
- piping and wiring

3.3.3 Component and unit tests. Individual components, subassemblies, and completed TECS units were tested by Keco at their Florence, Kentucky facility and by the government at Panama. The Keco test program was approved by the government, and was straight-forward in nature. As to be expected during a development effort, some problems showed up in the form of component failure.

Extracts taken from Keco's reports to VSE, which discuss tests and problems in sequence, follow. Included in these extracts are the results of government tests at Panama, and additional tests performed to determine the TECS unit capacity when power frequencies were increased above the original 61 Hz. All tests were accomplished during the period of June 1986 - April 1987.

- o An electrical interference on the over/under voltage sense circuit causes occasional shutdown of the inverter. No damage to the system has been experienced as a result of the shutdown, and circuit is being modified to improve noise immunity.
- o A single failure of one of the main power transistors was observed during testing. This is believed to have been caused by improper testing of the system and is being examined.
- o Overheating in the input EMI filter circuit appears centered on the series choke in the filter. Chokes wound with larger wire are being fabricated to correct this.
- o The second KC-2 controller has been installed in a modified TECS-18K Environmental Control Unit and the system has been tested at room temperature for basic operation. One problem in operation was identified, that being that the controller tripped out an overcurrent when the compressor was switched on by the thermostat in the TECS-18K. This was addressed by modifying the control box of the TECS-18K to delay the closing of the compressor contactor about one second after the thermostat operated. This allows time for the KC-2 to reset and then soft start the compressor.
- o The TECS-18K with KC-2 installed was tested for capacity in accordance with ASHRAE 16 Procedure except that the evaporator wet bulb temperature was 69°F instead of 67°F as called for by the ASHRAE Procedure. Measured capacity of the modified TECS-18K was 16,427.9 BTU's. As a comparison for this value, an unmodified TECS-18K (400HZ Model) was tested for capacity. Results for this unit were 18,437.1 BTU's \* \* \*. (VSE Note: see the "second" Table I, page 9, for test results) \* \* \*.
- o During the capacity tests, two failures occurred in the KC-2 controller. In both instances, the main power transistors in the KC-2 were damaged. Analysis of the failures showed that leakage current from collector to base in these transistors, which became worse at the elevated temperature required in the capacity test, caused a forward

biased second breakdown to occur when the TECS-18K was switched off. A modification was made to the base drive circuitry to absorb this leakage current, and the capacity test was performed without further problems.

- o The third KC-2 controller has been assembled and bench tested. No unexpected problems were encountered. The fourth KC-2 is partially assembled and should be completed during the next reporting period.
- o The bite indicator board first piece was assembled and tested without major difficulty arising. The three (3) additional pieces of the bite indicator have been assembled and tested. One piece was installed in the system during capacity testing.
- o The on-off cycling test, using the first KC-2 assembled, is proceeding, and approximately 43,000 cycles have been completed. One failure has occurred in the unit during this test. After about 33,475 cycles, one of the two N.T.C. varistors used to limit in-rush failed. This failure caused the KC-2 to shut down and stop powering the output load. No other components failed as a consequence of this failure.
- o The on/off cycling test of the first KC-2 soft start inverter has been completed. The unit operated for 50,302 cycles during the test and 3,983 cycles during set-up and prior to start of the test. One failure occurred during the test as previously reported. The test was performed over a period of 31 days with occasional interruptions.
- o The first TECS-18K modified for the KC-2 inverter completed performance and run-in tests required by Statement of Work and was shipped to the Army Tropic Test Center, Panama. A spare KC-2 inverter also completed performance and run-in testing and was shipped to the Tropic Test Center.
- o Keco's Technical Representative was present at the Tropic Test Center during the week of 22 September 1986 to assist with set-up and testing of the modified TECS-18K.
- o The fourth KC-2 inverter has been assembled and bench tested. Required run-in and performance tests have been completed and inverter will be prepared for shipment shortly.
- o The first KC-2, which was used for the on/off cycling test, has been examined--no concealed damage was found. The bite board has been installed and this unit is being tested at this time. One failure occurred during performance testing; the main switching transistor in the logic power supply failed. This failure is being investigated.
- o Testing of the fourth inverter was progressing until a failure occurred in the control power supply. The failure was apparently caused by the main switching transistor in the power supply and appears similar to the failures which recently occurred at the Tropic

Test Center in Panama. A different transistor with higher voltage rating is being tested and to date results have been good.

- o In response to a request by Ft. Belvoir personnel, a modified control program for the KC-2 controller is being prepared. This program change will raise the frequency applied to the electric motors of the TECS18K from the present value, 61 HZ, to 67 HZ. Presently the program is being debugged. A second capacity test of the TECS-18K is planned when this modification is complete.
- o During testing of the TECS-18K, it was noted that under some conditions the unit would begin to cycle the compressor on and off rapidly--about once per minute. This has been traced to a system problem which occurs during start-up of the unit. When the TECS-18K's thermostat requests that the compressor be turned off, the evaporator fan also stops momentarily. During this interval, the thermostat temperature rises slightly and in turn signals the compressor to restart. However, as soon as the evaporator fan begins to operate, the thermostat cools off and shuts down the compressor once again. The cure for this problem was to slightly insulate the thermostat by wrapping it with tape or covering it with heat shrinkable tubing.
- o The capacity test, using higher frequencies to drive the motors in the TECS-18K, has not yet been completed. The delay in performing this test has been the result of debugging the modified software for this type of operation, testing it, and scheduling of the capacity test chamber at Keco. This is not expected to be completed within the next reporting period. In addition to the capacity test, Keco will also perform a limited test of acoustic noise with the TECS-18K operating at the higher frequency for comparison.
- o To clarify and elaborate on the failure of the main switching transistor in the control power supply reported previously--the circuit uses this transistor to drive a small high frequency transformer, and in normal operation, exposes the transistor to a peak voltage of 330V (collector to emitter) that is well within the ratings of the TIPL 761 which was initially selected for this circuit \* \* \*. However, in operation, a rapid transient in voltage occurred as a consequence of the leakage inductance in the transformer each time the transistor switches. The magnitude of the transformer's leakage inductance could not be predicted accurately and consequently, the magnitude of the voltage could not be anticipated. This effect was examined carefully in early prototypes and found to be within acceptable limits for the TIPL 761. Subsequent units, however, showed some variation in this parameter and the voltage rating of this transistor was exceeded. The part selected to replace the TIPL 761 is the 2SC3551 \* \* \*. Results using this part have been very encouraging. There have been no recorded failures to date and checks of the voltage stress in circuit demonstrate a 150V or higher safety margin.
- o To clarify another item--the device which failed during the cycling test of the KC-2 was an N.T.C. Varistor (a negative temperature co-

efficient temperature sensitive resistor). This part decreases its resistance with increasing temperature; so as current through the device increases, thus raising its temperature, the electrical resistance decreases. The effect of this part in circuit is to initially present a high resistance to limit in-rush while charging the DC Bus Capacitor (this occurs while the part is still at room temperature) then lower its resistance when the normal running current causes it to heat up, thus reducing the voltage drop and power distribution in the varistor.

- o Several tests have been performed to measure the cooling capacity of the inverter aided TECS-18K environmental control unit. These tests have been run in order to evaluate the expected increase in capacity of the TECS-18K with higher output frequency settings of the KC-2 inverter. An early lesson learned in this effort was that the optimum setting of the expansion valve in the ECU changed for any changes in inverter frequency. The setting of this valve has substantial effects on the capacity of the ECU, and this resulted in having to repeat several of the tests to correct for this effect. Two tests run with the KC-2 frequency set at 66 Hz show the effect of the expansion valve; on 23 December 1986 the cooling capacity of the TECS-18K was measured and determined to be 16083 BTU/HR using the same valve setting as had been used at 61 Hz. Later the expansion valve was readjusted and with no other changes in the TECS-18K, the capacity was found to be 16471 BTU/HR; an increase of 388 BTU/HR.
- o The expected increase in ECU cooling capacity with increasing inverter frequency still has not been clearly seen in test results to date.
- o Results of capacity tests run to date are shown in Table 1. Work is continuing to understand the cause of the rather low values obtained in these tests using the KC-2.

TABLE 1: SUMMARY OF TECS-18K CAPACITY TESTS

Date of Test	Inverter Freq.	Capacity	Remarks
23 Dec 86	66 Hz	16,083.44	First Valid Test at 66 Hz
16 Jan 87	66 Hz	16,471.53	Readjusted Expansion Valve
20 Jan 87	61 Hz	16,665.79	Repeat of Original 61 Hz Test
23 Jan 87	66 Hz	16,497.76	Repeat of 66 Hz Test with Higher Superheat
30 Jan 87	65 Hz	16,334.59	Sealed small air leaks in center partition

- o Additional tests have been performed in accordance with Change Order A of VSE Purchase Order 65294 to measure the cooling capacity of the TECS-18K with the KC-2 soft start controller. These tests were repeated after it was noted that the expansion valve in the TECS-18K was not performing normally. The valve was repaired and the capacity tests made afterwards gave results in agreement with early expectations. - It is believed that this was the main cause of the unexpectedly low capacities measured previously. For reference, a summary of these latest tests is shown in Table 1.

TABLE 1: SUMMARY OF TECS-18K CAPACITY TESTS

Date of Test	Inverter Freq.	Capacity	Remarks
21 Feb 87	65 Hz	20,067 BTUH	None
24 Feb 87	61 Hz	18,761 BTUH	None

VSE NOTE: For comparison purposes, an unmodified split-package unit produced 18,437 BTUH under the same test conditions.

As was stated in a detailed report to VSE, Keco reached the following conclusions concerning the change of output frequency of the motor controller-logic network in relation to unit operation and capacity.

- o The results of this test indicate that no substantial degradation of ECU cooling capacity occurred when the KC-2 inverter was used to power the ECU. It is difficult to quantitatively measure the effects of the KC-2 on the ECU cooling capacity, as numerous modifications were made to the ECU to accommodate the controller. Numerous piping and airflow changes undoubtedly had some effect on the cooling capacity aside from the direct effects of the KC-2. However, the results obtained on 24 February 1987 taken with a 61 Hz output frequency indicate a value which is reasonably above the 18,000 BTU/HR rating of the original ECU, and as such looks to be a good indication that no significant reduction of cooling capacity resulted from use of the controller.
- o It is expected that an increase in output frequency (motor speed) would result in a significant increase in capacity and the data taken on 21 February 1987 appears to confirm this. No changes were made to the ECU for this test, only the KC-2 output frequency was raised to about 65Hz, and an increase of 1306 BTU/HR was observed (about 6.5%). Also of interest in this test data is an increase in the power drawn by the ECU (unit power in the data). This probably is a result of the increased power drawn by the compressor at higher speed as well as the increase in fan power for the evaporator and condenser. The 65Hz

frequency used in this test is not viewed as a critical value. The ECU was operated briefly with frequencies as high as 69Hz at room ambient and no detrimental effects were noted, though no data was taken. 65Hz was chosen as a test condition as it represented a large enough change to produce a measurable effect, but not so large that any damage or deterioration of the compressor would occur. Also since the output voltage of the KC-2 could not be increased beyond 208V, the amount of torque available from the ECU motors was decreasing for frequencies higher than 60Hz; this fact also tended to limit the frequency used for the test.

3.3.4 Manual deliveries. Keco delivered two manuals to VSE during their performance of the soft-start TECS effort. These manuals, accepted by the government during January 1987, were:

- o Technical Manual. Operation and Maintenance Instructions, KC-2 Transistorized Soft Start Controller.
- o Operator's Manual for Total Environmental Control System (TECS-18K) Modified For Soft Start, Variable Input Frequency Use.

#### 3.4 Soft-start variable capacity TECS.

3.4.1 Work effort and requirements. One previously manufactured 18,000 BTUH TECS unit, using a 1970s state-of-the electronic motor controller, was modified to the soft-start variable capacity TECS configuration. This work was performed by VSE, Zycron, and Maritime Dynamics, at their Alexandria, Virginia, West Haven, Connecticut, and Lexington Park, Maryland facilities, respectively. Unit tests were conducted by VSE before shipping the unit to Fort Belvoir, Virginia.

Specific requirements for this work effort were to use an electronic motor controller-logic network unit which would provide the soft-start variable capacity TECS configuration. The function of the motor controller-logic network unit was to convert 208 VAC, 3-phase 50/60 Hz or 400 Hz power to soft-start 208 VAC, 3-phase, 61 Hz power for operation of newly installed condenser and evaporator fan motors, and to provide variable frequency and voltage input power (maintaining a constant volt/frequency ratio) for operation of a newly installed compressor. The variable capacity motor controller-logic network was to vary the speed of the compressor from full speed (61 Hz) to 40% of full speed (24 Hz). The incorporation of BITE, and delivery of one spare motor controller-logic network unit, an operators manual, and operation and maintenance instructions were also required.

3.4.2 Major engineering changes and modifications. The major engineering changes and modifications resulting in the conversion of the previously manufactured 1970's TECS unit to the state-of-the-art soft-start variable capacity configuration were:



- o removal of old and unnecessary hardware:
  - 1970's electronics and controls.
  - 400 Hz motors and compressor.
  - piping and wiring.
- o repackaging of retained hardware to accommodate new components.
- o installation of new components:
  - Motor controllers (one for fan motors and one for compressor) and logic network.
  - BITE.
  - 50/60 Hz motors and compressors.
  - piping and wiring.

3.4.3 Component and unit tests. VSE and it's subcontractors tested all components and units for which they had design and/or integration responsibilities.

Tests of the soft-start variable capacity TECS components and completed unit revealed two problems:

- o Logic network (Maritime Dynamics report to VSE). On several occasions, the control electronics suffered IC failures. There was no discernable pattern in the failures other than the logic family 74 HC (x)(x). Various solutions, such as decreasing output loads, increasing power supply decoupling capacitors, yielded slight improvements in failure rates. The problem was ultimately traced to the power supply. On Power Up, the supply would occasionally overshoot (13-volts on the 5-volt line) and result in I.C. failures. Replacement of the power supply has eliminated the I.C. failure problem.
- o Complete TECS unit test (VSE report to Belvoir). Several false fan shut-down indications, but no actual fan failure. The fan overcurrent sensing circuit was adjusted for higher tolerance. No further problems were experienced.

3.4.4 Manual deliveries. Soft-start variable capacity TECS manuals delivered were:

- o AC Motor Speed Controls, SPUD 200 and SPUD 500, Instruction Manual (208 Volt Operation), For Variable AC Motor Speed Control For All Types Of 1 HP and 5 HP Three Phase Motors (Zycron).
- o Modified Total Environmental Control System, TECS 18, Control Electronic Manual (Maritime Dynamics).

3.5 Feasibility study and repackaging study. Keco was tasked by VSE to conduct these studies on 9K, 18K, and 36K BTUH horizontal and vertical compact air conditioners (environmental control units - ECUs) manufactured to military

specification MIL-A-52767. The results of Keco's studies were provided to VSE in a detailed 103 page report. This report was endorsed by VSE and provided to Belvoir as part of task order 0001. Details of this report may be requested from:

Commander  
Belvoir Research, Development and  
Engineering Center (ATTN: STRBE-FE)  
Fort Belvoir, VA 22060-5606

Briefs of each study follow.

3.5.1 Feasibility study. This study determined the feasibility of using commercial off-the-shelf components in selected military standard air conditioners (see 3.5). The major results of this study, as extracted from the Keco report, are:

- o No standard off-the-shelf electrical motors suitable for use in the ECUs studied were found. The requirements of MIL-M-1412 are believed to be prudent for this application and effectively prohibit use of any standard motor. Many potential suppliers of these motors were willing to modify current designs to meet these requirements but this does not appear to offer any significant cost reduction as compared to the present qualified motors.
- o An acceptable substitute for the relays used in the ECUs appears to have been found in the IEC contactors now available. Lack of fungus-proofing and limited temperature range are problems that are believed to be solvable, however, no significant cost reduction appears possible except in the event that a substantial quantity of a modified IEC contactor were procured e.g. (10,000 pcs). Additionally, the availability of 28 VDC coils for these items seems to be a little uncertain, but this should be remedied in time. A substantial cost savings was made by eliminating most of the circular connectors used in the ECUs. This should result, also, in some improvement in reliability but maintainability will probably suffer. Optionally certain strategic connectors may be added to improve maintainability. Examination of the requirements for circuit breakers in the ECUs verified that a cost reduction is possible but, in general, commercial parts are physically larger which would require careful examination to verify compatibility with the ECU design. Detailed examination of the various trip characteristics is also recommended.
- o The use of off-the-shelf motor controllers is not considered feasible due to space constraints as well as certain environmental requirements.

3.5.2 Repackaging study. This study provided six complete drawing packages for the conversion of six military standard air conditioners (see 3.5) to the soft-start TECS configuration. Some of the results of this study, extracted from Keco's report are:

- o The ECUs considered in this study have been modified to provide adequate space for custom designed motor controllers.
- o Complete drawing packages and revised refrigeration schematics have been prepared for the 9000; 18000; and 36000 BTUH horizontal and vertical ECUs. These were modified to permit capacity modulation by compressor cycling rather than hot gas bypass. This results in reduced (VSE added: average) power consumption when operating in cool mode and simplified unit piping. A reduction in cost of these ECUs was realized by removal of the liquid line solenoids and back pressure regulators as well as the savings in labor. Coil frost switches have been included in all ECUs for protection against frosting of evaporator coils during abnormal operating conditions, and this was connected into the control circuitry for the ECU to inhibit compressor operation under these conditions. Dampers in the condenser fan discharge were retained.
- o As a result of this repackaging, the need for a "class" designation to identify the input power rating of the ECU has been shown to be unnecessary, thus producing a substantial simplification in logistics, stocking, and purchasing. The control circuits of the ECUs have been revised to accommodate the motor controllers and to maximize the commonality of these systems; resulting in reduced manufacturing time and more rapid servicing.

Finally, a cost comparison has been made which shows that the revised units are somewhat more expensive than the original design, though it must be remembered that the motor-controller addition is required by contract. The unit without the motor controller has been reduced in price due primarily to elimination of components. Efforts to substitute commercial components for military components had a negligible effect on price. The total spectrum of fielded electrical generators may be altered (simplified), and the Army's approach to operations could change in a variety of ways that cannot be predicted at this time.

#### 4. CONCLUSIONS

- o The soft-start variable capacity TECS is considerably more complicated and more expensive than the soft-start unit, and does not appear to offer many additional advantages.
- o Military standard 18,000 BTUH split-package air conditioners, conforming to MIL-A-52693, can be successfully modified to the soft-start Total Environmental Control Systems (TECS) concept.
- o One previously manufactured experimental split-package TECS unit was successfully modified to the soft-start variable capacity TECS concept.

- o Sufficient technology is available to modify existing military standard air conditioner designs to the soft-start or soft-start variable capacity TECS concepts.
- o Most commercial off-the-shelf air conditioning components are not suitable for use in military standard 9,000, 18,000 and 36,000 BTUH air conditioners.
- o Existing military standard horizontal and vertical 9,000, 18,000, and 36,000 BTUH air conditioners can be repackaged for installation of electronic motor controllers.
- o Military standard air conditioner designs using electronic motor controllers will be more expensive than the original design. But, reduction in energy consumption is expected to result in considerable saving in life-cycle costs of the units.

#### 5. RECOMMENDATIONS

- o Belvoir should initiate tasks for the advanced development of soft-start TECS units to be used for further tests and preproduction runs.
- o Belvoir should continue to use the proven military standard components in military standard air conditioners. Cost savings would accrue from substituting commercial connectors for the military standard connectors.
- o Belvoir should conduct testing, under controlled conditions, to verify the magnitude of energy savings of the TECS over a similar, conventionally controlled, military standard air conditioner.